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Ivanov A.V.;

Electromagnetic dynamic calculation.

Applied Electromagnetics

One of the major criteria of reliability of a power supply system is ability to keep level of tension at short circuits in a network. Current-limiting reactors (fig. 1) are used for decrease of short-circuit currents. The problem of the precise calculation of such reactors is connected first of all with the presence of the effect of current replacement.

For the account of the phenomenon of current replacement each of *nc* of the coaxial cylinders of a phase winding separated by cooling channels, is divide by the number of *ns* parallel calculation sections. The electric equivalent circuit of a reactor`s winding with calculation contours is presented on fig. 2.

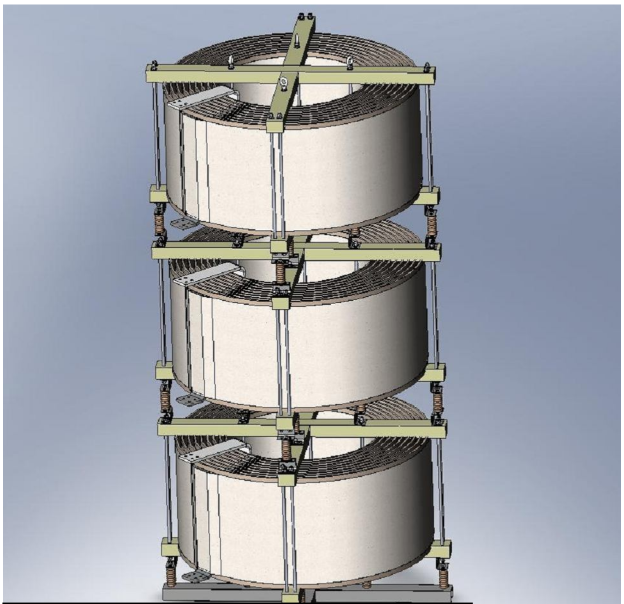

Fig. 1. The current-limiting reactor.

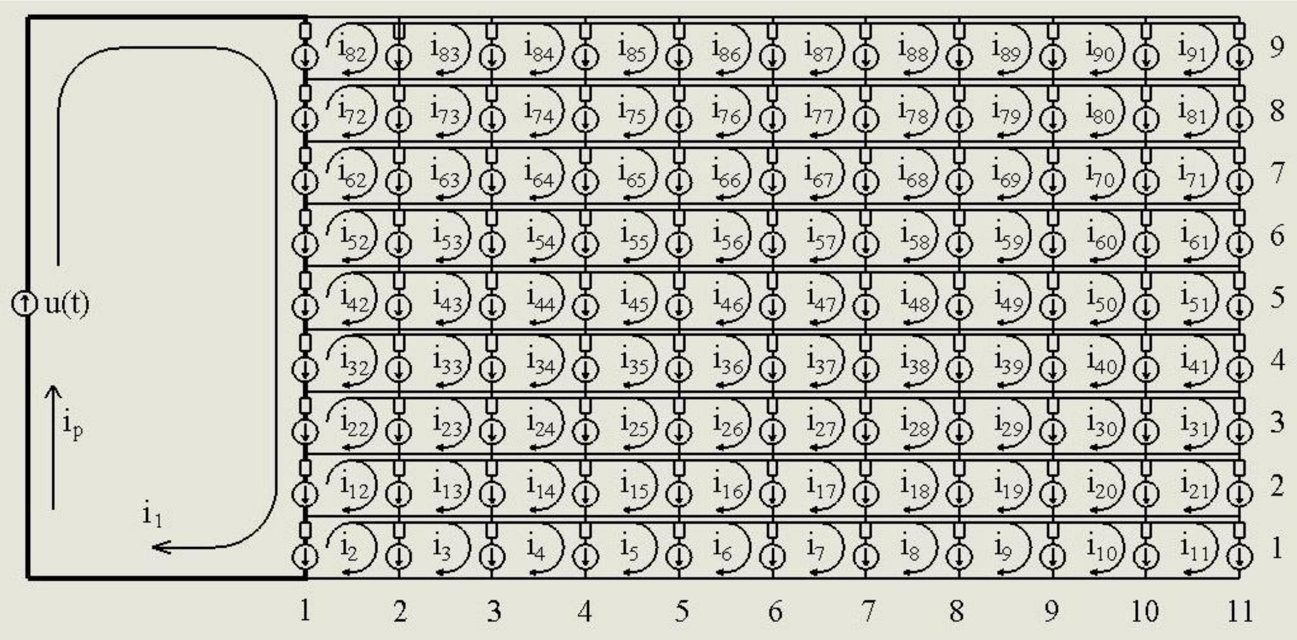

Fig. 2. The equivalent circuit of a reactor`s winding of a made of aluminium tape.

EMF in the section, is defined on the basis of the results of calculation of a magnetic field as:

$$e_{sk} = -\frac{d\Psi_{sk}}{dt} = -\sum_{q=1}^{n} \frac{\partial \Psi_{sk}}{\partial i_q} \cdot \frac{di_q}{dt}$$

where Ψ_{sk} - flux linkage of sections with a magnetic field.

The method of finite-element modeling of the magnetic field developed in the Ivanovo state power university was applied to calculate private derivatives $\frac{\partial \Psi_{sk}}{\partial i_q}$. This method is based on the library which provides the function of generation, calculation and the analysis of model of a magnetic field of the device under investigation study for the base programming system. The tabular processor MSExcel with a built-in interpreter Visual Basic is chosen as the base environment. The program code is created, allowing to generate model of a reactor on basis of design characteristics the limited. This program also fulfills serial calculations of the magnetic field created by each loop current *q* separately.

Being a problem linear, the following equation is used

$$\frac{\partial \Psi_{sk}}{\partial i_q} = \frac{\Psi_{sk}}{i_q} \qquad (2)$$

The system of the equations for the scheme fig. 1 looks like:

$$\begin{cases} u(t) + \sum_{s=1}^{ns} e_{s1} = i_1 \cdot \sum_{s=1}^{ns} R_{s1} - \sum_{s=1}^{ns} \sum_{r=2}^{nk} R_{s1} \cdot i_{sr} \\ e_{sk} - e_{s1} = R_{sk} \cdot i_{sk} - R_{s1} \cdot i_1 + R_{s1} \cdot \sum_{r=2}^{nk} i_{sr} \Bigg|_{k=2}^{k=nk} \Bigg|_{s=1}^{s=ns} \end{cases} . \qquad (3)$$

Taking into account the equations (1) and (2) systems of will be transformed to:

$$\begin{cases} \sum_{q=1}^{n} \left(\sum_{s=1}^{nc} \frac{\partial \Psi_{s1}}{\partial i_q} \right) \frac{di_q}{dt} = u(t) - i_1 \cdot \sum_{s=1}^{nc} R_{s1} + \sum_{s=1}^{nc} \sum_{r=2}^{ns} R_s \\ \sum_{q=1}^{n} \left(\frac{\partial \Psi_{sk}}{\partial i_q} - \frac{\partial \Psi_{s1}}{\partial i_q} \right) \frac{di_q}{dt} = R_{s1} \cdot i_1 - R_{sk} \cdot i_{f(s,k)} - \end{cases}$$

. (4)

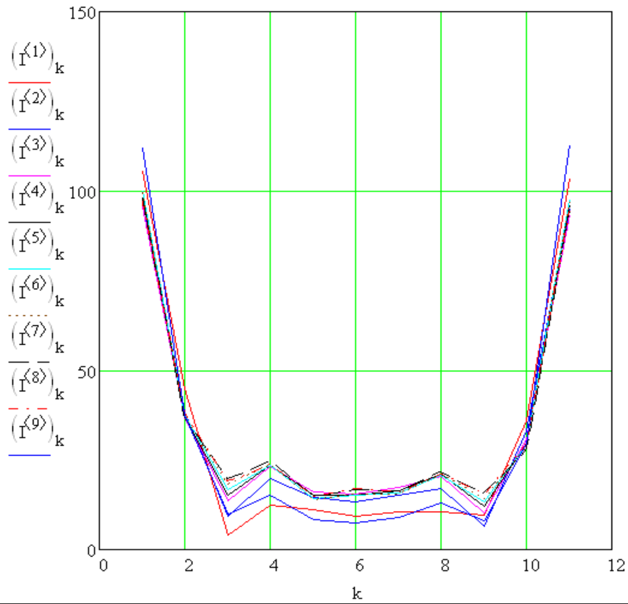

Fig. 3. Diagram`s of currents in winding cylinders.

Where R_{sk} is the resistance of winding *k* of cylinder *s*; i_q a current of contour *q* of an equivalent circuit; f (s, r) - function of recalculation of a double index of a current in number of a contour of an equivalent circuit; u (t) - the applied voltage.

The system of the equations (4) looks like:

$$[L]\cdot\left[\frac{di}{dt}\right]=[U], \tag{5}$$

Where $[L]$ is a square matrix of inductances; $\left[\frac{di}{dt}\right]$ a vector derivative of loop currents on time; $[U]$ - a vector of the right parts.

The solution of the system of the equations (5) allows to obtain curve changes of the currents sections within the time. Diagram of currents distributions on sections of seen cylinders in the established mode is shown on fig. 3. From drawing it is visible, that the current in all cylinders is superseded in extreme sections. The values of the currents allow to carry out exact calculation of losses and inductance of a reactor. The results of inductance calculation differ from the results of experimental measurements by Δ =1,75 % that testifies to high accuracy of calculation. A more sophisticated model, could be used for calculation of magnetic fields of several windings of a reactor. In this case the equivalent circuit is composed of 3 star net works with neutral having Ro, given in the fig.3. The equation system (3) is supplemented by 2 analogous systems. There is no substantial complication of the mathematics, but the matrix (L) functioning might be involved by the number of equations growing. That`s why it is necessary to cut off the number of segments computated, this influening the precision of the computation. To control the precision of the HT winding sections inductivity calculations a cast resin transformer 1600 kVA 10/0.4 Δ/Y (fig. 4) were carried out on different distances. At the same time, analogous calculations using the library of final-element modulation were accomplished. The difference was no more than 5-6%. On the basis of the three phase reactor model, a number of consecutive computations. Was accomplished in order to determine an optimum interphase distance (fig. 5-6) and phase feed circuit configuration.

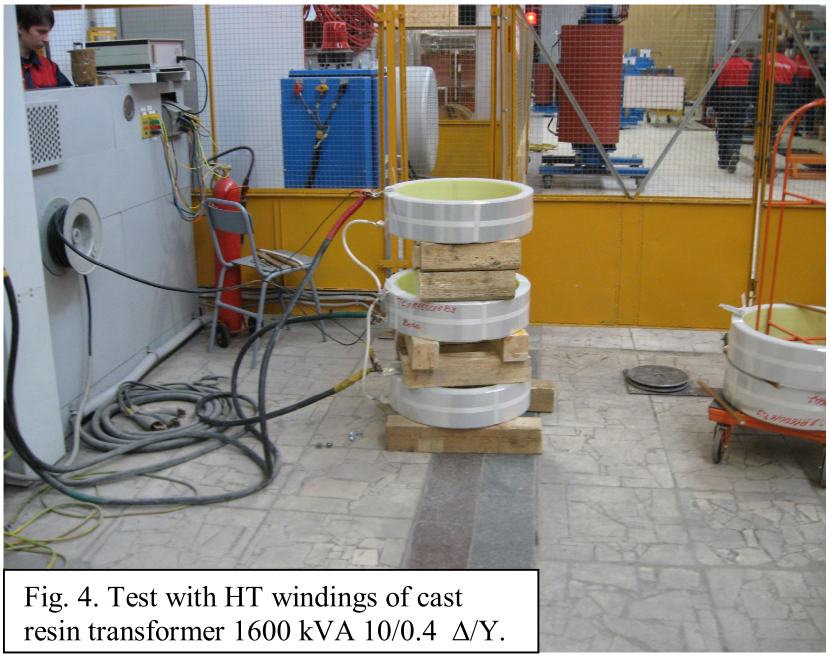

Fig. 4. Test with HT windings of cast resin transformer 1600 kVA 10/0.4 Δ/Y.

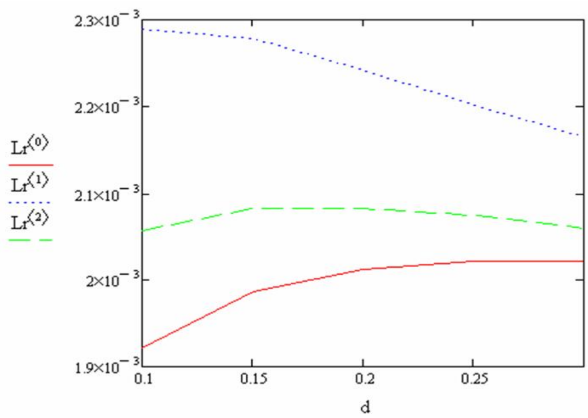

Fig. 5. Relation between inductance L of reactor`s windings and their inter-axis distance, d when being winded one-way direction.

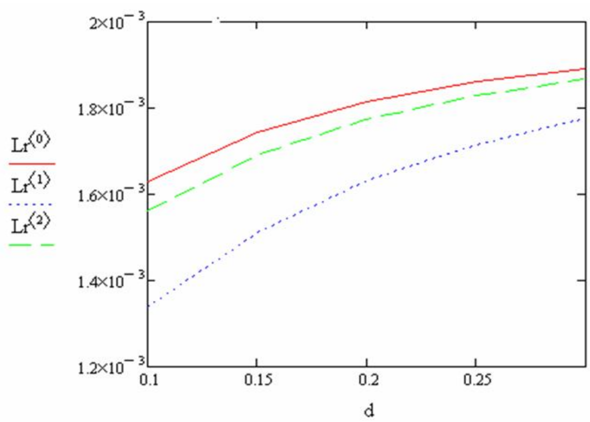

Fig. 6. Relation between inductance L of reactor`s windings and their inter-axis distance, d of windings, a middle one being winded in the opposite direction.

Each of the figures 5 and 6 represent 3 graphics, corresponding to 3 windings. Obviously, when the distance between the winding becomes longer, the inductivity changes, which could be explained by the reduced influence of the interinductance. The curves asymptotically run to the values corresponding to inductivity of a single winding which makes possible to fix an optimum distance.

The library only permits modulation of 2 dimension (flat parallel and axis-symmetrical) static magnetic fields. It was used in the described case to resolve the problem for non-stationary magnetic fields, taking into account the strong effect of current exclusion.

It is worth noting, that this example could not be considered as computation of non-stationary field of a solid conductor, because each cylinder of a phase winding is made of 3-4 coils of aluminum band, and there is an isolation material in between them. That`s why if the cylinder is considered solid (in Elcut, for instance) a 11-13% error will appear.

In view of this, the method of modulation proposed could be accepted as an optimum one.

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